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Grabowsky et al.

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(54) **AIRCRAFT FLIGHT DATA ACQUISITION AND TRANSMISSION SYSTEM**

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(*) Notice: Under 35 U.S.C. 154(b), the term of this patent shall be extended for 0 days.

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(51) **Int. Cl.**[7] **H04B 7/00**; G06F 17/40; G06F 13/00

(52) **U.S. Cl.** **701/14**; 701/35; 455/431

(58) **Field of Search** 701/14, 3, 24, 701/35; 455/431, 422, 456

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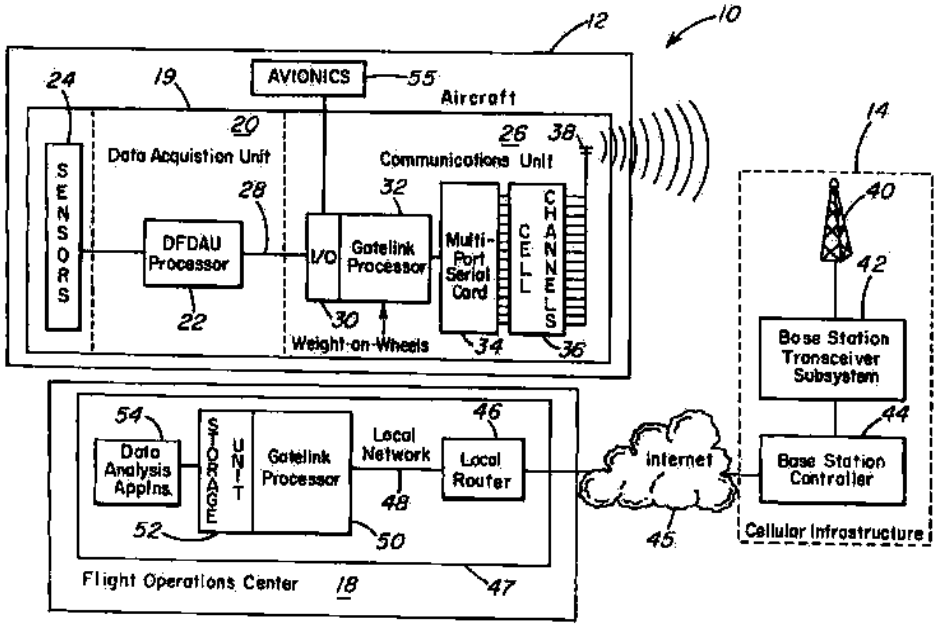
(57) **ABSTRACT**

An aircraft data transmission system used with an aircraft having a data acquisition unit. The system includes a communications unit located in the aircraft and in communication with the data acquisition unit. The system also includes a cellular infrastructure in communication with the data communications unit after the aircraft has landed. The system further includes a data reception unit in communication with the cellular infrastructure.

33 Claims, 10 Drawing Sheets



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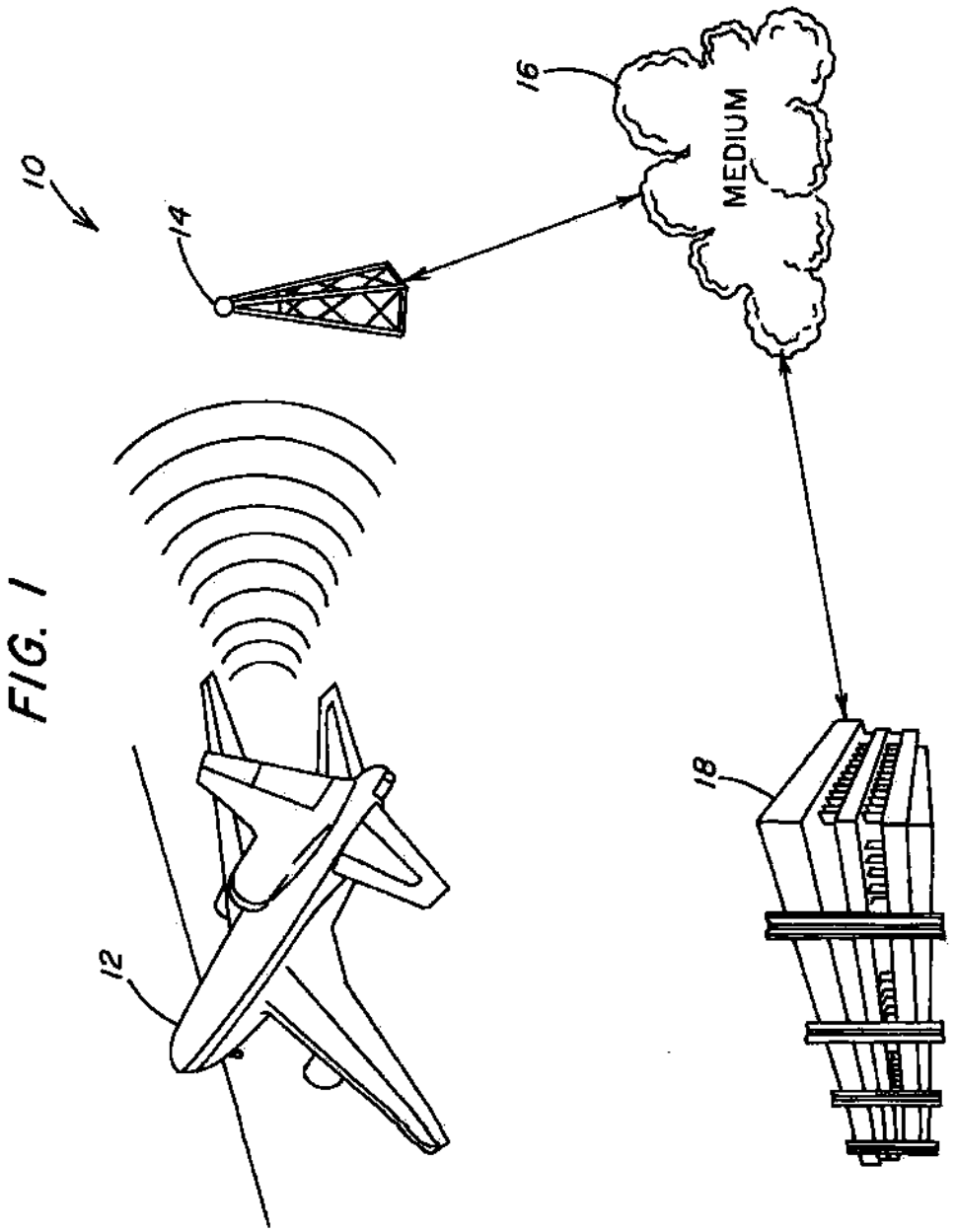

FIG. 1

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FIG. 2

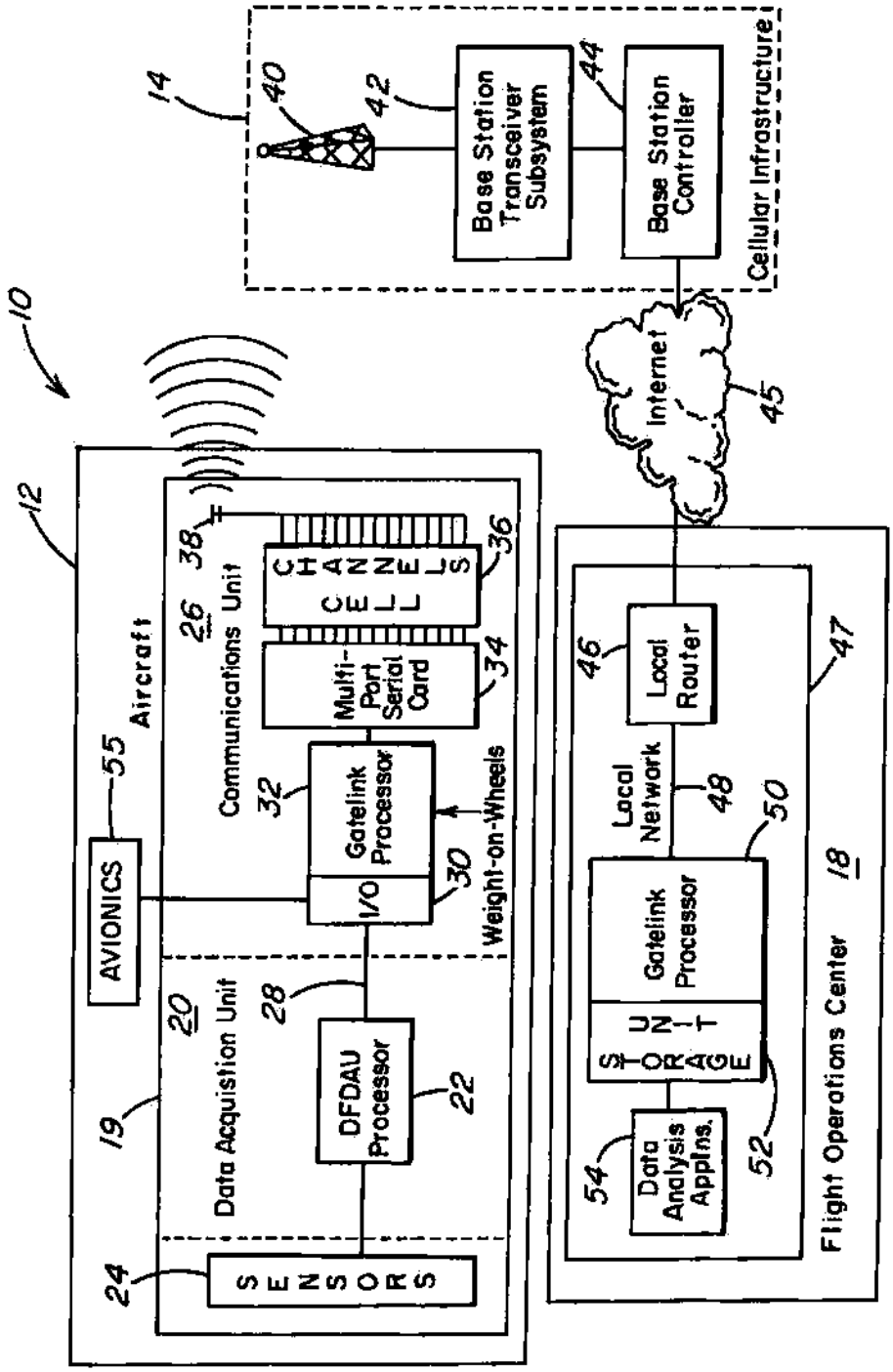

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FIG. 3

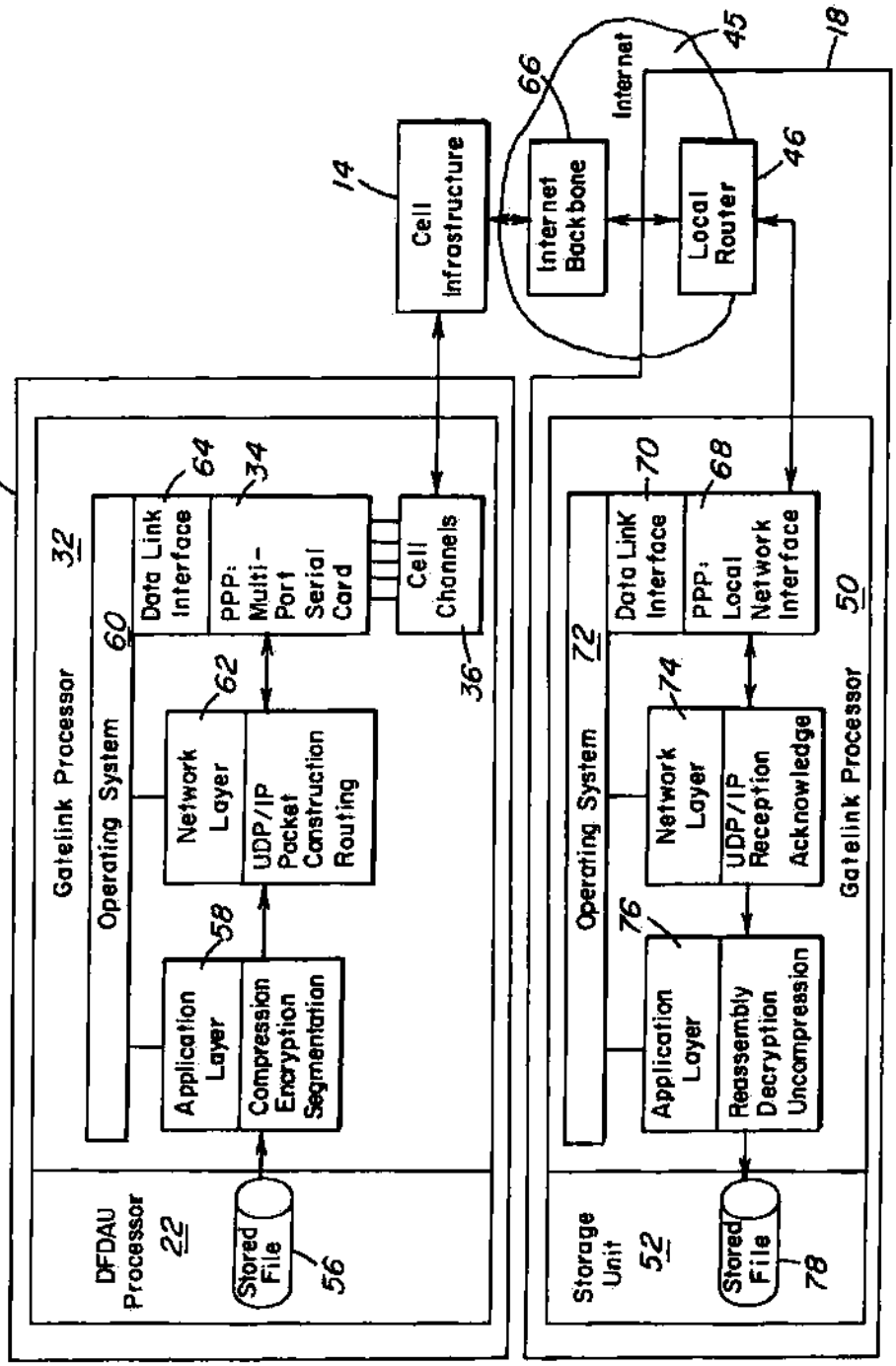

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FIG. 4

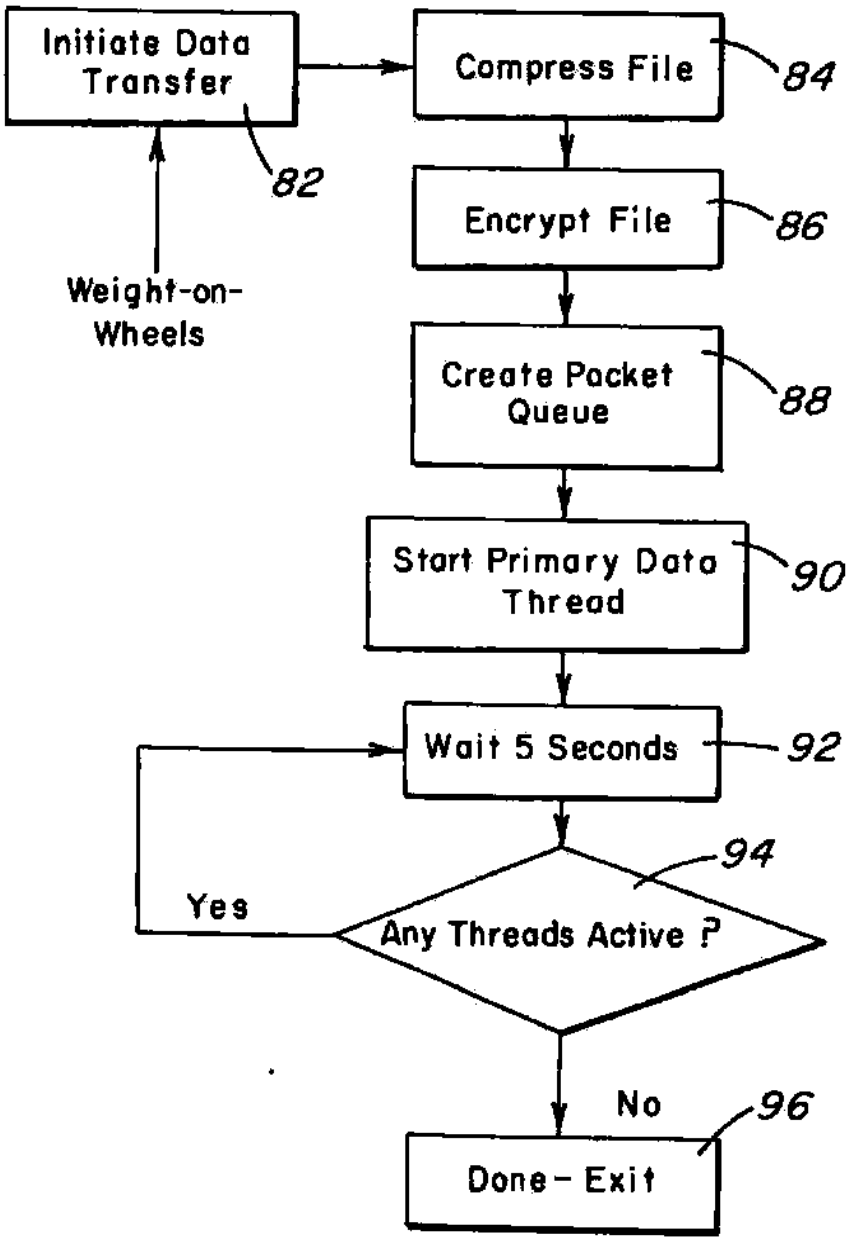

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FIG. 5

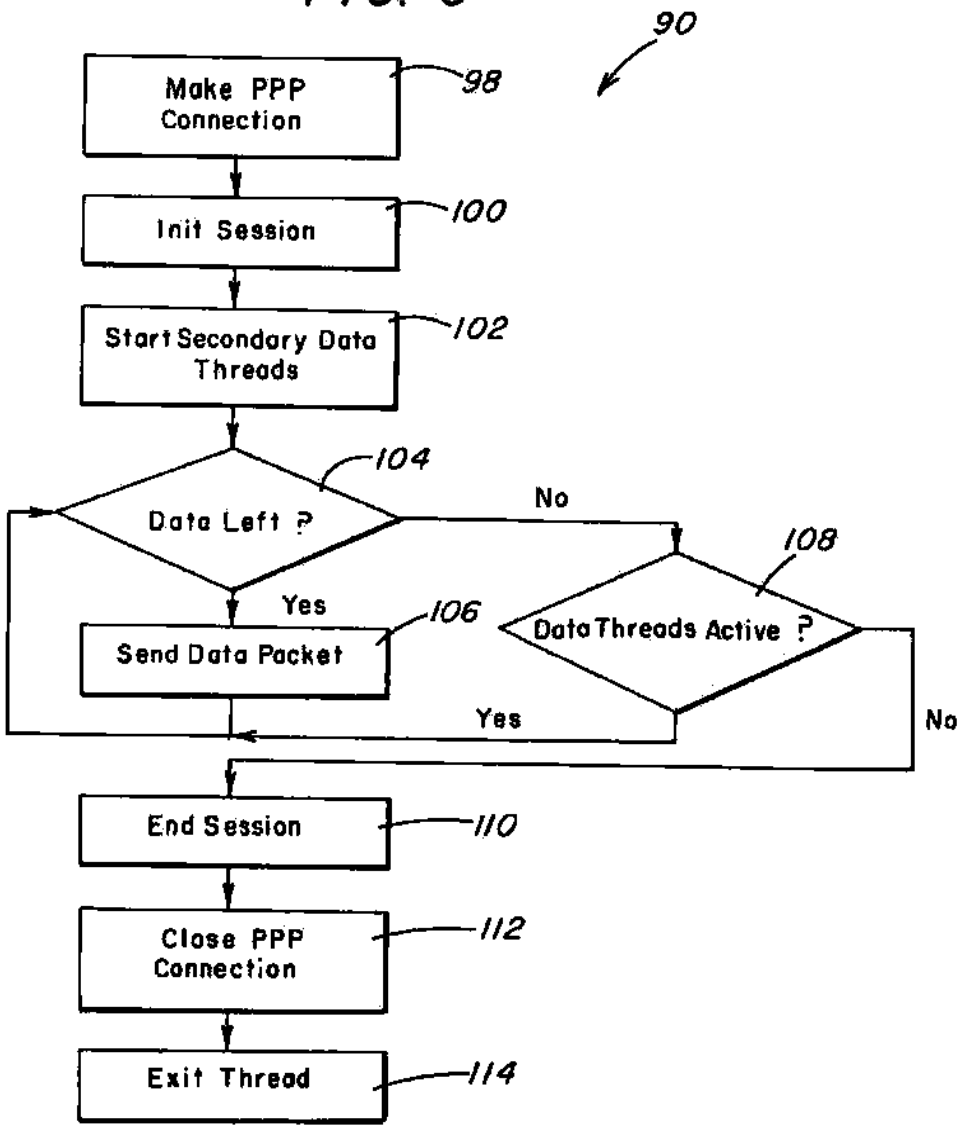

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FIG. 6

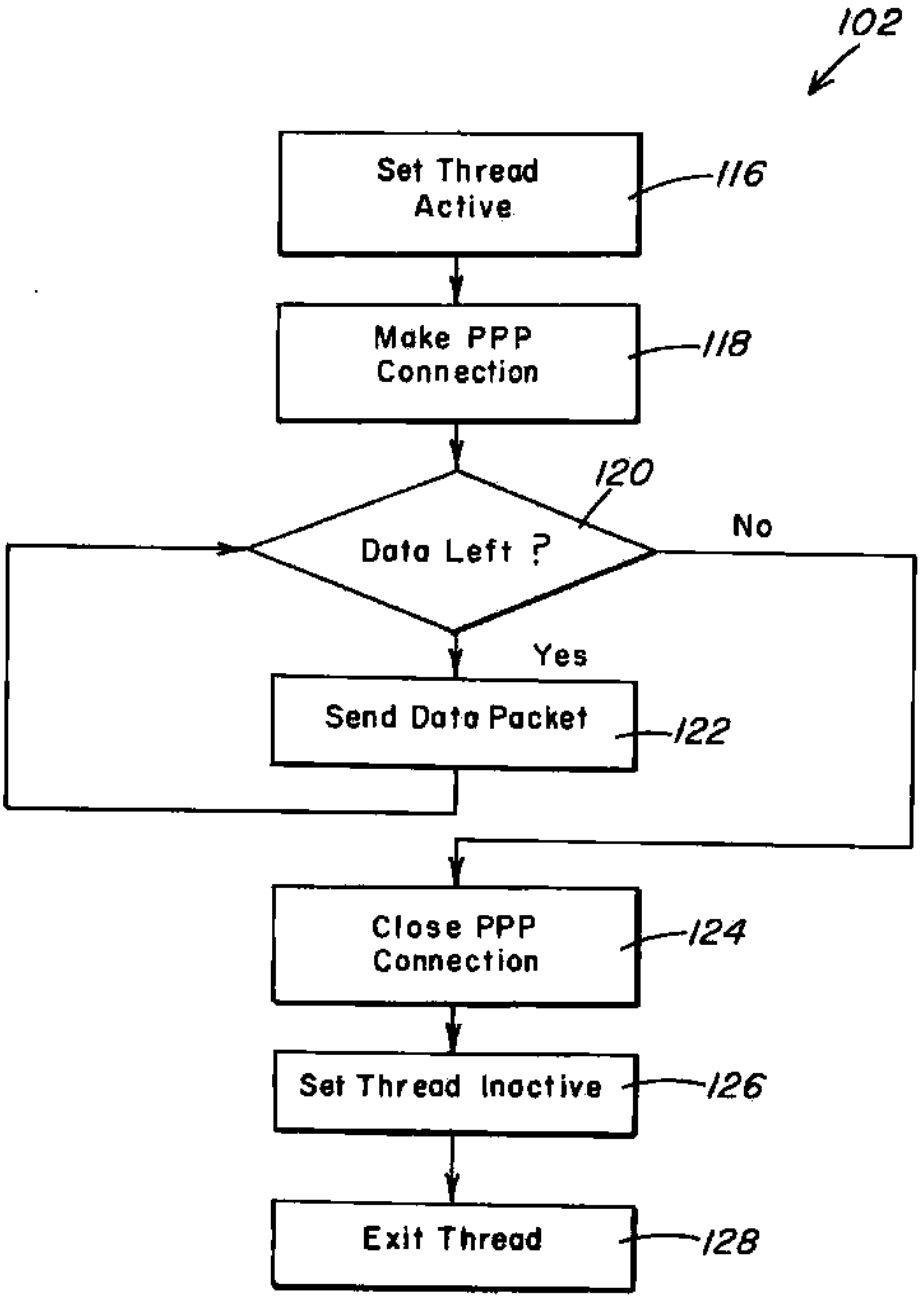

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FIG. 7

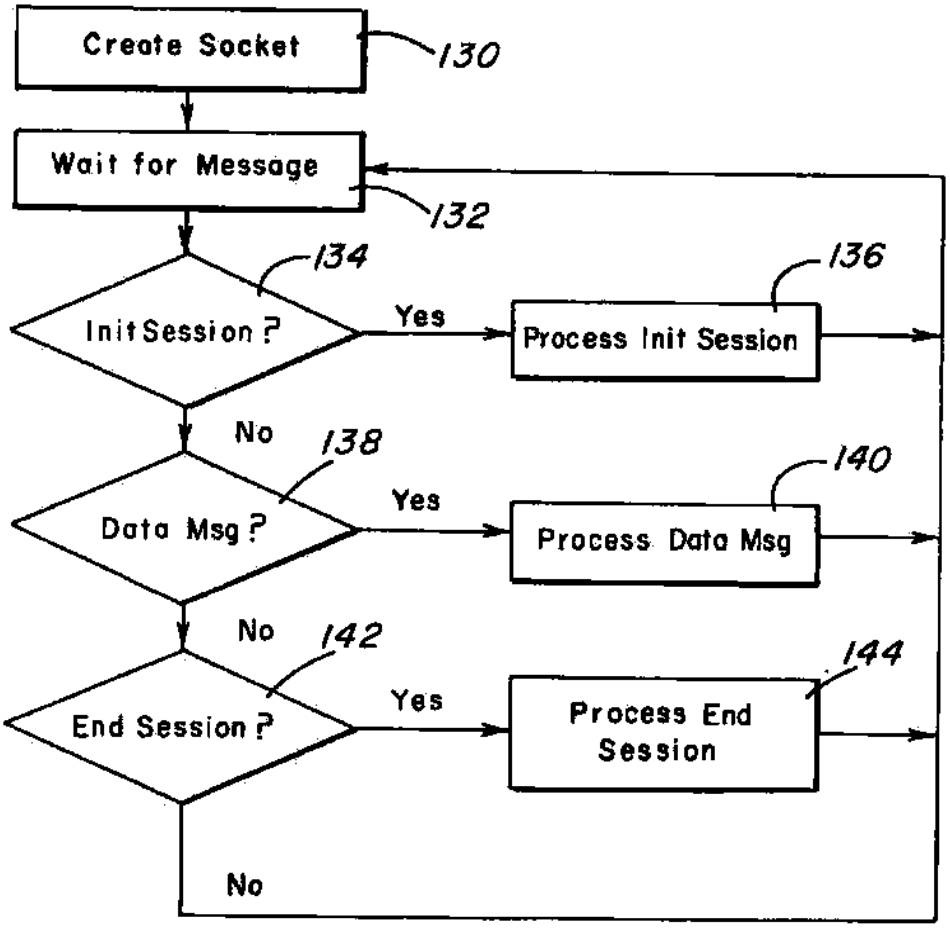

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FIG. 8

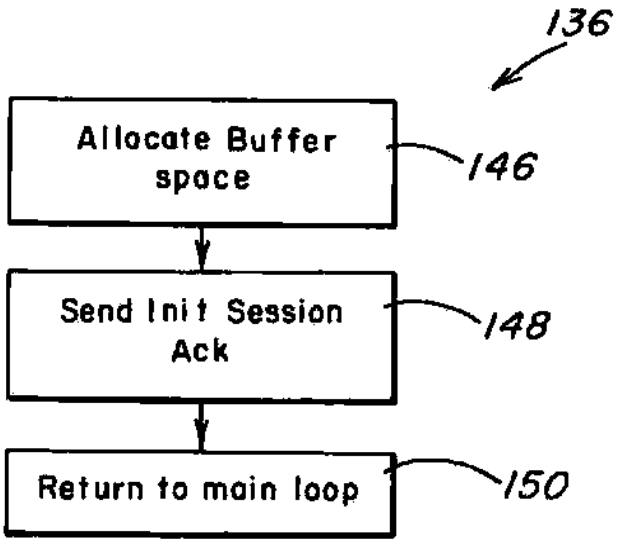

FIG. 9

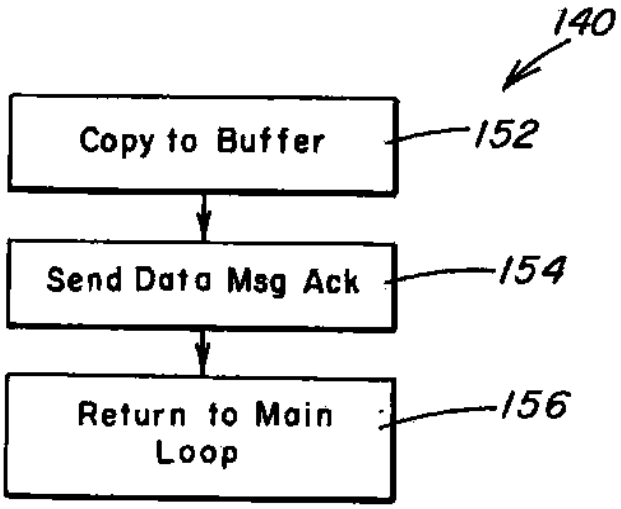

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FIG. 10

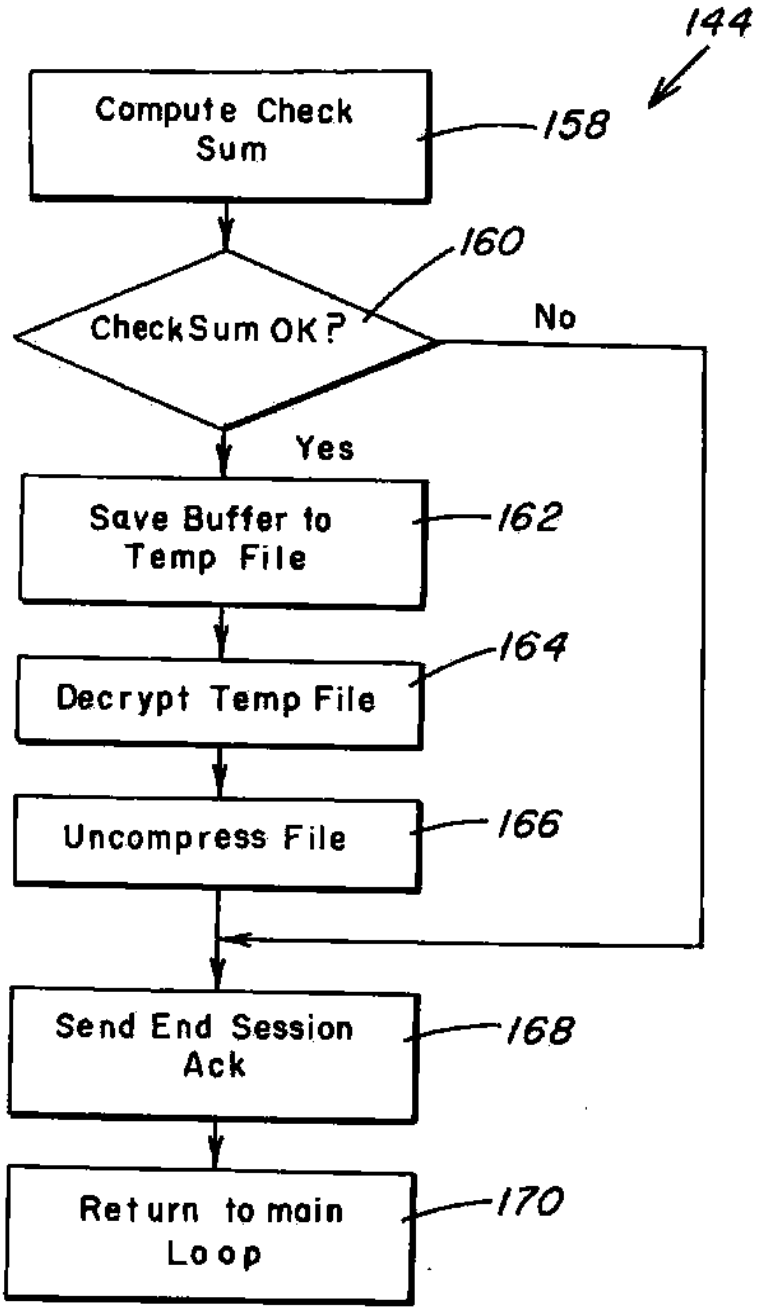

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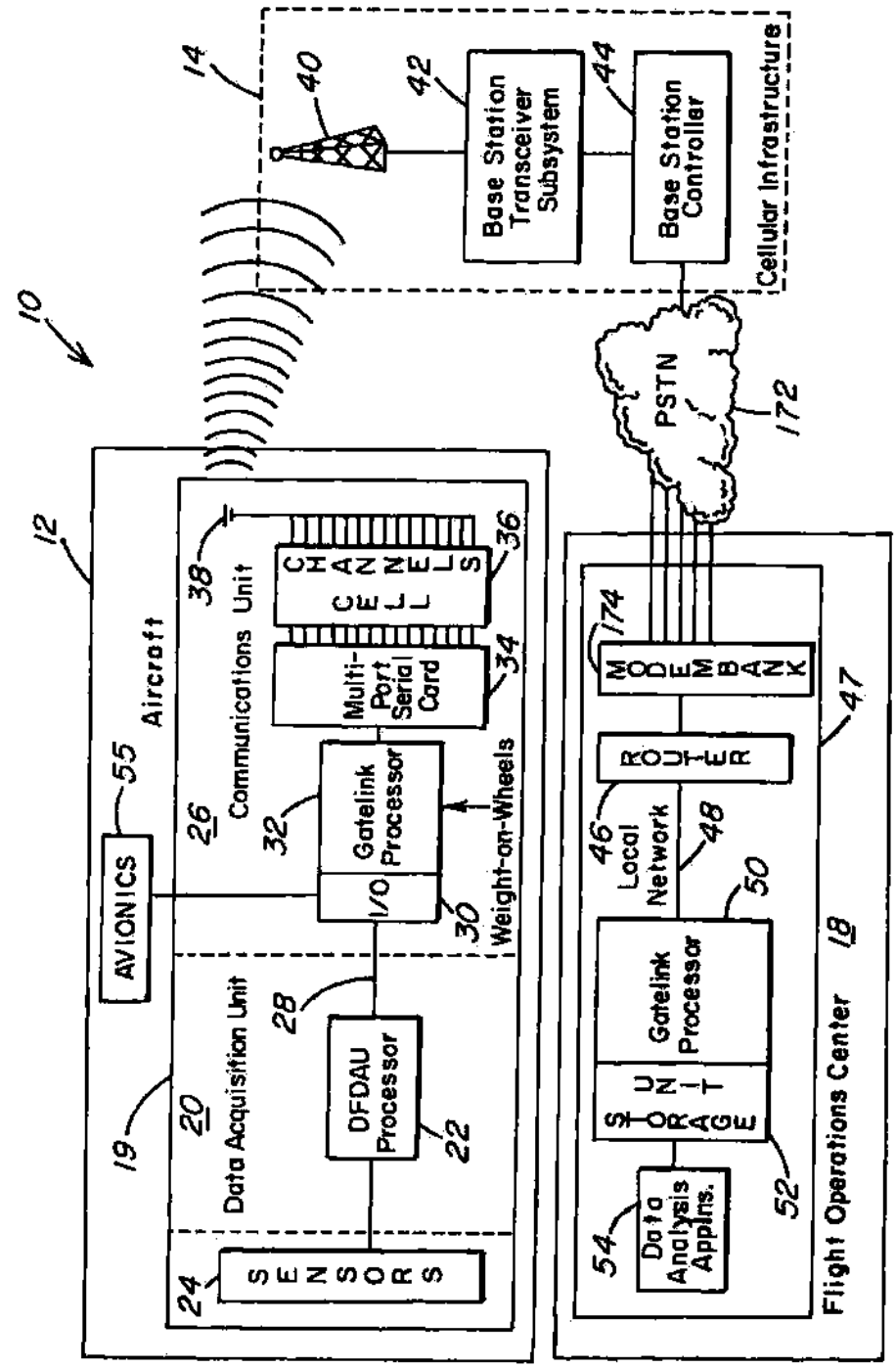
FIG. 11



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AIRCRAFT FLIGHT DATA ACQUISITION AND TRANSMISSION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

(Not Applicable)

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

(Not Applicable)

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed generally to an aircraft flight data acquisition and transmission system and, more particularly, to an on-board cellular data transmission system.

2. Description of the Background

It is common for aircraft to generate records of data relating to flight and performance parameters for each flight of the aircraft. The data typically relate to parameters such as air speed, altitude, vertical acceleration, heading, time, etc. The data are utilized in the event of an accident or a near-accident and to assist in maintenance of the aircraft by detecting faulty components or gradual deterioration of a system or component, to assist in reviewing crew performance, and to assist in logistical planning activities such as scheduling and routing.

Aircraft data are typically gathered by a digital flight data acquisition unit (DFDAU). The DFDAU typically stores the data on magnetic or magnetic-optical media. When the aircraft lands, ground personnel board the aircraft, remove the media, and mail the media to a flight operations center (FOC). The manual removal and posting of the data adds a significant labor cost, yields less than desirable data delivery reliability, and results in a significant time delay before the data are useful for analysis.

It is known to use radio frequency (RF) transmissions to transmit data relating to an aircraft. Such teachings, however, require substantial investments to construct the RF transmission systems required for such a system to work. Furthermore, it is very expensive to create redundancy in such a system.

It is also known to transmit data relating to an aircraft via a telephone system located in a terminal. Such a system, however, requires that the aircraft be docked at the gate before transmission begins, thereby resulting in a substantial delay in the transmission. Furthermore, such a system requires an added step of transmitting the data from the aircraft to the terminal telephone system, increasing the cost of installing, operating, and maintaining such a system.

Thus, there is a need for an aircraft data transmission system that automatically transfers flight data from an aircraft to a flight operations center with little or no human involvement and which relies on a reliable wireless delivery system.

SUMMARY OF THE INVENTION

The present invention is directed to an aircraft data transmission system used with an aircraft having a data acquisition unit. The system includes a communications unit located in the aircraft and in communication with the data acquisition unit. The system also includes a cellular infrastructure in communication with the data communications unit after the aircraft has landed. The system further includes a data reception unit in communication with the cellular infrastructure.

The present invention represents a substantial advance over prior aircraft data acquisition and transmission systems. For example, the present invention has the advantage that it requires little expense to implement because it uses well-known technology and the cellular infrastructure which is already in place. The present invention also has the advantage that it can transmit data over multiple parallel channels to achieve the necessary transmission bandwidth and achieve a low data transmission time. The present invention has the further advantage that it does not require a dedicated data link between the aircraft and the flight operations center and/or an airport terminal.

BRIEF DESCRIPTION OF THE DRAWING

For the present invention to be clearly understood and readily practiced, the present invention will be described in conjunction with the following figures, wherein:

FIG. **1** illustrates an aircraft data acquisition and transmission system;

FIG. **2** is a block diagram illustrating a more detailed embodiment of the system illustrated in FIG. **1**;

FIG. **3** is a block diagram illustrating data flow through the system illustrated in FIG. **2**;

FIG. **4** is a flowchart illustrating a method carried out by the gatelink processor in the aircraft;

FIG. **5** is a flowchart illustrating a method of performing the start primary data thread step of FIG. **4**;

FIG. **6** is a flowchart illustrating a method of performing the start secondary data threads step of FIG. **5**;

FIG. **7** is a flowchart illustrating a method of operating the gatelink processor in the flight operations center;

FIG. **8** is a flowchart illustrating a method of performing the initialize session process step of FIG. **7**;

FIG. **9** is a flowchart illustrating a method of performing the data message process step of FIG. **7**;

FIG. **10** is a flowchart illustrating a method of performing the end session process step of FIG. **7**; and

FIG. **11** is a block diagram illustrating another embodiment of the system illustrated in FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

It is to be understood that the figures and descriptions of the present invention have been simplified to illustrate elements that are relevant for a clear understanding of the present invention, while eliminating, for purposes of clarity, other elements found in a typical communications system. It can be recognized that other elements are desirable and/or required to implement a device incorporating the present invention. For example, the details of the cellular communications infrastructure, the Internet, and the public-switched telephone network are not disclosed. However, because such elements are well known in the art, and because they do not facilitate a better understanding of the present invention, a discussion of such elements is not provided herein.

FIG. **1** illustrates an aircraft data acquisition and transmission system **10**. An aircraft **12**, which has stored flight data, is illustrated after landing. The aircraft **12** transmits flight data as cellular communications signals to a cellular infrastructure **14**. The cellular infrastructure **14** acts as a

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communications channel to the communications medium **16**. A flight operations center **18** is connected to the medium **16** by any conventional connectivity medium such as, for example, a leased line. Once the cellular connections are made via the medium **16** data can flow bidirectionally from or to the aircraft.

FIG. **2** is a block diagram illustrating a more detailed embodiment of the system **10** illustrated in FIG. **1**. The aircraft **12** includes a data system **19** having a data acquisition unit **20**. The data acquisition unit **20** includes a digital flight data acquisition unit (DFDAU) processor **22**, which includes a storage media for storing flight data in a digital format. The DFDAU processor **22** receives signals from sensors **24** which sense parameters such as air speed, altitude, vertical acceleration, heading, time, etc. The flight data are transferred to a communications unit **26** via a bus **28**. The bus **28** is connected to an I/O interface **30** in the communications unit **26**. The I/O interface **30** can be a standard bus interface such as, for example, an ARINC **429** bus interface.

The I/O interface **30** is connected to a gatelink processor **32**. The processor **32** can be a general purpose processor such as a personal computer, a microprocessor such as an Intel Pentium® processor, or a special purpose processor such as an application specific integrated circuit (ASIC) designed to operate in the system **10**. The processor **32** is responsive to a weight-on-wheels signal, which acts as an interrupt signal to signal the processor **32** to initiate transmission or reception of the data when the aircraft **12** has landed. Upon receipt of the weight-on-wheels signal from the landing gear of the aircraft **12**, the processor **32** prepares the flight data for transmission and transmits the data to a multi-port serial card **34**. Each I/O port of the card **34** is attached to a cell channel which can open, sustain, and close a physical, over-the-air channel to the cellular infrastructure **14**. The cell channels **36** can transmit simultaneously and can thus transmit data in parallel. Each cell channel **36** is connected to an antenna matching network and a post amplifier (not shown). An antenna **38** is installed in the aircraft **12** so as to optimize free space radiation to the cellular infrastructure **14**.

The data are transmitted over a cellular airlink using the physical layer modulation of the cellular infrastructure **14**. The cellular infrastructure **14** includes an antenna **40**, which is within free-space radiating range of the aircraft **12**. The antenna **40** is connected to a base station transceiver subsystem **42**. The subsystem **42** is connected to a base station controller **44** which has a direct connection via a router (not shown) to the Internet **45**. The flight data are transmitted via the Internet **45** to the flight operations center **18**.

A local router **46** in a data reception unit **47** of the flight operations center **18** is connected to the Internet **45**, such as via a connection to the backbone of the Internet **45**. The router **46** connects a local area network **48** to the Internet **45**. The local area network can be of any type of network such as, for example, a token ring network, an ATM network, or an Ethernet network. A gatelink processor **50** is connected to the network **48** and receives the flight data for storage in an attached storage unit **52**. The storage unit **52** can be any type of unit capable of storing data such as, for example, a disk array or a tape drive. The storage unit **52** makes the flight data available to data analysis applications **54** which can analyze and/or report the flight data to a user.

Data transfer can also occur from the flight operations center **18** to the aircraft **12**. The data are transmitted via the Internet **45** and the cellular infrastructure **14** and received by the antenna **38**. The serial card **34** receives the data from the cell channels **36** and the processor **32** outputs the data, via the I/O interface **30**, to avionics **55**.

FIG. **3** is a block diagram illustrating data flow through the system **10** illustrated in FIG. **2**. The flight data is stored in the DFDAU processor **22** as a stored file **56**. An application layer **58** of an operating system **60** of the gatelink processor **32** compresses, encrypts, and segments the data. The operating system **60** can be any type of operating system suitable such as, for example, UNIX. A typical stored file may be compressed from approximately 40 Mbytes to approximately 4 Mbytes. Compression may be done by any compression method such as, for example, the method embodied in the PKZIP® compression utility, manufactured by PKWARE, Inc. Encryption can be accomplished using any suitable asymmetric (public key) or symmetric encryption method such as, for example, the method embodied in Data Encryption Software (DES), manufactured by American Software Engineering or the methods in the RC2, RC4, or RC5 encryption software manufactured by RSA Data Security, Inc. During segmentation individual datagrams of, for example, 1024 bytes are formed and indexed for subsequent reassembly.

The operating system **60** passes the datagrams to a network layer **62** which constructs UDP/IP packets from the datagrams by adding message headers to the datagrams. The network layer **62** then routes the packets to one of up to 16 peer-to-peer protocol (PPP) threads running within the operating system **60** at a data link layer interface **64**. The PPP threads convey the packets to the multi-port serial card **34** for transmission to the backbone **66** of the Internet **45** via the cell channels **36** to the cellular infrastructure **14**. The packets are received from the Internet **45** by the local router **46** in the flight operations center **18**. The network layer **62** receives acknowledgments of received packets from the gatelink processor **50** in the flight operations center **18**. The network layer **62** also re-queues packets that are dropped before reaching the gatelink processor **50**.

The local router **46** in the flight operations center **18** receives the packets and routes them to the gatelink processor **50**. A local network interface **68** receives the packets and a data link layer interface **70** of an operating system **72** passes the packets to a network layer **74** of the operating system **72**. The operating system **72** can be any type of suitable operating system such as, for example, UNIX. The network layer **74** sends acknowledgments of successful packet deliveries to the gatelink processor **32**. The network layer **74** also removes the UDP/IP headers and passes the datagrams to an application layer **76**. The application layer **76** reassembles, decrypts, and uncompresses the datagrams to restore the flight data to its original form. The application layer then passes the data to a stored file **78** in the storage unit **52**. The functions performed by the aircraft **12** and the flight operations center **18** are similarly interchangeable when data is transferred from the flight operations center **18** to the aircraft **12**.

FIG. **4** is a flowchart illustrating a method carried out by the gatelink processor **32** in the aircraft. At step **82**, the gatelink processor **32** receives a weight-on-wheels interrupt which signals that the aircraft has landed, and the data transfer is initiated. The application layer **58** compresses the flight data at step **84** and encrypts the data at step **86**. At step **88**, the data is segmented into datagrams and UDP/IP packets are constructed. The packets are then placed in a packet queue. The packets are then ready for transmission as a fixed number of threads, corresponding to the number of cell channels **36**. At step **90**, the primary data thread is

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started to make the initial call and open the communications channel to the flight operations center **18**. A wait state at step **92** is invoked for a predetermined period of time (5 sec.) and at step **94**, the processor **32** determines if any threads are active, i.e. if there are any packets that haven't been transmitted or have been transmitted and dropped. If there are no packets remaining, the method is completed at step **96**. If there are packets remaining, the method enters the wait state at step **92** and subsequently determines if any threads are active at step **94**.

FIG. **5** is a flowchart illustrating a method of performing the start primary data thread step **90** of FIG. **4**. At step **98**, the point-to-point protocol (PPP) connection is initiated for the primary data thread through one of the cell channels **36** and the gatelink session is initiated at step **100**. The secondary data thread transmissions are started at step **102**. At step **104**, it is determined if any packets are left in the primary data thread to be transmitted. If so, the next packet in the primary data thread is transmitted at step **106**. If no packets are left to transmit in the primary data thread as determined at step **104**, it is determined if any of the secondary data threads are active at step **108**. If so, the process returns to step **104** and repeats step **108** until no threads are active. If no threads are active, the gatelink session is ended at step **110** and the PPP connection for the primary data thread is closed at step **112**. At step **114**, the primary data thread step **90** is completed.

FIG. **6** is a flowchart illustrating a method of performing the start secondary data threads step **102** of FIG. **5**. The method is carried out in parallel for each secondary data thread. At step **116**, the thread is set to active so that the processor **32** can determine if any threads are active at step **108** of FIG. **5**. The PPP connection for the secondary data thread being transmitted is initiated at step **118**. At step **120**, it is determined if any packets remain in the data thread. If so, the packet is transmitted at step **122**. If no packets remain in the data thread, the PPP connection is closed at step **124** and the thread is set to inactive at step **126**. The method is completed at step **128**.

FIG. **7** is a flowchart illustrating a method of operating the gatelink processor **50** in the flight operations center **18**. At step **130**, a socket is opened to allow the operating system **72** in the processor **50** to receive and transport messages across the Internet **45**. At step **132**, the processor **50** waits for a message from the Internet **16**. When a message is received, the processor **50** determines if the message is a session initialization message at step **134**. If the message is a session initialization message, the processor **50** executes the session initialization process at step **136**. If the message is not a session initialization message at step **134**, the processor **50** determines if the message is a data message at step **138**. If the message is a data message, the processor **50** executes the data message process at step **140**. If the message is not a data message, the processor **50** determines if the message is an end session message at step **142**. If the message is an end session message, the processor **50** executes the end session process at step **144** and then returns to step **132** to wait for additional messages..

FIG. **8** is a flowchart illustrating a method of performing the initialize session process step **136** of FIG. **7**. The processor **50** allocates buffer space for subsequent data reception at step **146**. The processor **50** then sends a session initialized data acknowledgment to the processor **32** at step **148**. At step **150**, the flow returns to step **132** of FIG. **7**.

FIG. **9** is a flowchart illustrating a method of performing the data message process step **140** of FIG. **7**. At step **152**, the received data message is copied to a buffer and an acknowledgment of the data received is sent at step **154**. At step **156**, the flow returns to step **132** of FIG. **7**.

FIG. **10** is a flowchart illustrating the steps included in the end session process step **144** of FIG. **7**. At step **158**, the checksum is computed for the received data to check the integrity of the data. The checksum is checked at step **160** and, if it is correct, the processor **50** saves the buffer to a temporary file at step **162**. The processor **50** then decrypts the file at step **164** and uncompresses the file at step **166**. The processor **50** sends an end session acknowledge message to the processor **32** at step **168** and at step **170**, the flow returns to step **132** of FIG. **7**. If the checksum is not correct, the processor **50** sends an unsuccessful end session message, which notifies the processor **32** to resend the data.

FIG. **11** is a block diagram illustrating another embodiment of the system **10** illustrated in FIG. **1**. The operation of the system **10** of FIG. **11** is similar to that described in conjunction with the system **10** of FIG. **2**. However, the flight data is transmitted from the cellular infrastructure **14** to the flight operations center **18** via the public-switched telephone network **172**. A modem bank **174** receives the data via the PSTN **172**. The data is then routed by the router **46** to the processor **50** via the network **48**. The modem bank **174** can have a modem dedicated to receive data transmitted by one of the cell channels **36**.

While the present invention has been described in conjunction with preferred embodiments thereof, many modifications and variations will be apparent to those of ordinary skill in the art. For example, although the system has been described hereinabove as transferring data from the aircraft, the system can also be used to transfer data to the aircraft with no modifications in the system. Also, the system may be used to transmit data while the aircraft is in flight. Furthermore, the system may be used without encryption and without data compression prior to sending data. The foregoing description and the following claims are intended to cover all such modifications and variations.

What is claimed is:

1. An aircraft data transmission system, the aircraft having a data acquisition unit, comprising:

a communications unit located in the aircraft and in communication with the data acquisition unit;

a cellular infrastructure in communication with said communications unit after the aircraft has landed, wherein the communication is initiated automatically upon landing of the aircraft; and

a data reception unit in communication with said cellular infrastructure.

2. The system of claim **1** wherein said data reception unit is in communication with said cellular infrastructure via the Internet.

3. The system of claim **1** wherein said data reception unit is in communication with said cellular infrastructure via the public switch telephone network.

4. The system of claim **1** wherein said communications unit has at least one modem in communication with said cellular infrastructure and said data reception unit has at least one modem in communication with said cellular infrastructure.

5. The system of claim **1** wherein said communications unit includes:

a processor;

a serial card in communication with said processor;

at least one cell channel in communication with said serial card; and

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at least one antenna in communication with said cell channel.

6. The system of claim 1 wherein said cellular infrastructure includes:

an antenna;

a transceiver subsystem in communication with said antenna; and

a controller in communication with said transceiver subsystem.

7. The system of claim 1 wherein said data reception unit includes:

a router; and

a processor in communication with said router, said processor having a storage unit.

8. A data system for an aircraft, comprising:

a digital flight data acquisition unit in communication with at least one sensor;

a processor in communication with said digital flight data acquisition unit;

a serial card in communication with said processor; and

a plurality of cell channels in communication with said serial card, said cell channels for transmitting data via a cellular infrastructure after the aircraft has landed, wherein the communication between the cell channels and the serial card is initiated automatically upon landing of the aircraft.

9. The system of claim 8 further comprising an antenna in communication with said cell channels.

10. The system of claim 8 wherein said processor includes a personal computer.

11. The system of claim 8 wherein said processor includes an ASIC.

12. The system of claim 8 wherein said processor includes a microprocessor.

13. The system of claim 8 wherein said processor has an I/O interface in communication with said digital flight data acquisition unit.

14. An aircraft, comprising:

a digital flight data acquisition unit in communication with at least one sensor; and

a communications unit in communication with said digital flight data acquisition unit, said communications unit including:

a processor in communication with said digital flight data acquisition unit;

a serial card in communication with said processor; and

a plurality of cell channels in communication with said serial card, said cell channels for transmitting data via a cellular infrastructure after the aircraft has landed, wherein the communication between the cell channels and the serial card is initiated automatically upon landing of the aircraft.

15. An aircraft data transmission system, the aircraft having a data acquisition unit, comprising:

means for transmitting data from the data acquisition unit via a cellular infrastructure after the aircraft has landed, wherein transmission of the data is initiated automatically upon landing of the aircraft; and

means for receiving said data from said cellular infrastructure.

16. The system of claim 15 wherein said means for transmitting data includes a processor.

17. The system of claim 15 wherein said means for receiving data includes a processor.

18. A method of transmitting aircraft flight data from an aircraft, comprising:

receiving flight data from a data acquisition unit;

transmitting said flight data via a cellular communications infrastructure after the aircraft has landed, wherein the cellular communications infrastructure is accessed automatically upon landing of the aircraft; and

receiving said transmitted flight data.

19. A computer-implemented method of transmitting aircraft flight data from an aircraft, comprising:

receiving flight data from a digital flight data acquisition unit;

processing said flight data to prepare said data for transmission; and

transmitting said processed data via a cellular infrastructure after the aircraft has landed, wherein the cellular infrastructure is accessed automatically upon landing of the aircraft.

20. The method of claim 19 further comprising receiving said transmitted data at a flight operations center.

21. The method of claim 20 further comprising receiving said transmitted data and transmitting said received data via the Internet before receiving said transmitted data at a flight operations center.

22. The method of claim 20 further comprising receiving said transmitted data and transmitting said received data via the public-switched telephone network before receiving said transmitted data at a flight operations center.

23. The method of claim 19 wherein processing said flight data includes:

compressing said flight data;

encrypting said flight data;

segmenting said flight data; and

constructing packets of data from said segmented flight data.

24. The method of claim 19 wherein receiving said transmitted data includes:

acknowledging receipt of said transmitted data;

reassembling said received data;

decrypting said reassembled data;

uncompressing said decrypted data; and

storing said uncompressed data.

25. A computer-implemented method of transmitting aircraft flight data from an aircraft, comprising:

receiving flight data from a digital flight data acquisition unit;

processing said flight data to prepare said data for transmission; and

transmitting said processed data via a cellular infrastructure after the aircraft has landed, wherein processing said flight data includes:

receiving a weight-on-wheels signal;

initiating a data transfer;

compressing said flight data;

encrypting said compressed data;

creating a packet queue;

starting a primary data thread;

waiting a predetermined period of time;

determining if any threads are active;

repeating, when threads are active, the steps of waiting a predetermined period of time and determining if any threads are active; and

exiting processing said flight data when no threads are active.

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26. The method of claim 25 wherein starting a primary data thread includes:

initiating a PPP connection;

initiating a transfer session;

starting at least one secondary data thread;

determining if data remains in the primary data thread;

sending said data when data remains in the primary data thread;

determining if data threads are active when no data remains in the primary data thread;

repeating, when said threads are active, the step of determining if data remains in the primary data thread;

ending said session when no threads are active;

closing said PPP connection; and

exiting starting a primary data thread.

27. The method of claim 26 wherein starting at least one secondary data thread includes:

(a) setting the secondary data thread to active;

(b) initiating a PPP connection;

(c) determining if data remains in the secondary data thread;

(d) sending a data packet when data remains;

(e) repeating step c when data remains;

(f) closing said PPP connection when no data remains;

(g) setting the secondary data thread to inactive;

(h) exiting starting at least one secondary data thread; and

(i) repeating steps a through h for each secondary data thread.

28. The method of claim 27 wherein repeating steps a through h includes repeating steps a through h in parallel for each said secondary data thread.

29. A computer-implemented method of transmitting aircraft flight data from an aircraft, comprising:

receiving flight data from a digital flight data acquisition unit;

processing said flight data to prepare said data for transmission; and

transmitting said processed data via a cellular infrastructure after the aircraft has landed; and

receiving said transmitted data at a flight operations center, wherein receiving said transmitted data includes:

creating a socket;

receiving a message;

determining if said message is an initialization message;

initiating a session when said message is an initialization message;

determining if said message is a data message when said message is not an initialization message;

processing said message when said message is a data message;

determining if said message is an end session when said message is not a data message;

processing said message when said message is an end session; and

repeating, when said message is not an end session message, the step of receiving a message.

30. The method of claim 29 wherein initializing a session includes:

allocating buffer space;

sending an initiation session acknowledgment; and

returning to receiving a message.

31. The method of claim 29 wherein processing said message when said message is a data message includes:

copying said message to a buffer;

sending a data message acknowledgment; and

returning to receiving a message.

32. The method of claim 29 wherein processing said message when said message is not an end session includes:

computing a checksum;

determining if said checksum is valid;

saving a buffer to a temporary file;

decrypting said temporary file;

uncompressing said temporary file;

sending an end session acknowledgment; and

returning to receiving a message.

33. A computer readable medium having stored thereon instructions which when executed by a processor, cause the processor to perform the steps of:

receiving flight data from a digital flight data acquisition unit in an aircraft;

processing said flight data to prepare said data for transmission; and

transmitting said processed data via a cellular infrastructure when said aircraft has landed, wherein the cellular infrastructure is accessed automatically upon landing of the aircraft.

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